ON THE DECISION MATRIX AND THE JUDGEMENT PROCESS; A DEVELOPMENTAL DECISION EXAMPLE

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ABSTRACT

The paper points out that in a decision task involving the selection of a system from a number of competing systems, a single number or figure of merit is usually inadequate to describe the merits of a given system and that a matrix of numbers representing the important parameters is required. A description is given of the parameters in this matrix. Rules are given for reducing the matrix and for drawing conclusions from the reduced matrix. An example involving a developmental decision is included to illustrate the process.

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INTRODUCTION

While the general method of decision-making presented herein has broader application than just to the developmental decision problem, it is discussed in connection with this problem to enhance clarity through dealing with the concrete rather than the abstract.

Systems are generally evaluated on the basis of their ability to perform some prescribed mission or missions. The representation of each system by a single number, like a figure of merit or a cost-effectiveness value would simplify the selection process. However, as pointed out in Ref. 1, this is usually inadequate to the task, and the decision maker should be supplied with a group of numbers for each system being compared. This group of numbers will be called the decision matrix. If one lists in the decision matrix all the factors that have a bearing on the selection, the matrix often becomes excessively unwieldy and confusing. On the other hand, too brief a list might eliminate an item essential to a proper decision. The purpose of this discussion is (a) to indicate the parameters that should be included in the decision matrix, (b) to discuss the procedure for reducing the matrix, and (c) to provide rules for drawing conclusions from the reduced matrix.

The rules for the matrix reduction and the judgment processes are considered to represent only an initial effort. Amplification and refinement of the rules can be expected as experience with these processes grows, involving a wider variety of cases and the contributions of people with greater insight.

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CHOICE OF PARAMETERS FOR DECISION MATRIX

The decision matrix should be complete in the sense that all information having an important bearing on the choice should be included. The number of parameters in the decision matrix can be kept in hand by combining under a single generic parameter a number of related parameters representing sub-items under the generic parameter.

This combining of a number of related parameters into a single parameter can be done by employing a figure of merit. A brief discussion of figures of merit is given in the Appendix. It is important in selecting the subparameters that are associated with any given generic parameter that there exists a true relationship; in order words, one should try to avoid mixing apples and oranges under a single figure of merit, but should limit the process to various kinds of oranges. The following are the parameters I believe appropriate to a decision on system development.

Decision Parameters

- Mission initial operational date (IOC): The date on which a mission operational capability is required is a major factor in setting the urgency for the decision on system selection and the state of art chosen.
- Decision date: This is obtained by subtracting the estimated time required for R&D and total system construction and assembly from the mission IOC date. It provides an estimate of the time available for research and exploratory engineering to improve the state of technology or the confidence in a new technology before a decision is required.
- System R&D cost: This is a measure of the investment risk in a new system.
- Mission cost effectiveness: This is a major factor in determining the worth of a new system. It can be expressed in two ways, depending on the situation appropriate to the problem.
  - (a) The cost to accomplish a prescribed objective; (e.g., in a study of the relative worth of competing aircraft propulsion systems, the cost effectiveness may be measured by the cost to transport a given amount of payload a given distance over a stated number of years).
  - (b) A measure of mission accomplishment for a given total investment in the mission; (e.g., the size of space station that can be built on the moon in terms of weight of equipment delivered for a given budget allotment).

If the system under analysis is part of a more complex system required for the mission (e.g., a propulsion system in an airplane) then the mission costs should include the R&D and procurement costs of the system under analysis and also the mission operation costs and any R&D and procurement costs associated with the modification or procurement of the total system that may be pertinent to the case under consideration.

The effect of system reliability on mission cost may be handled in two ways.

(a) When mission costs are extremely high or mission failure not permissible because of human cargo, differences in basic reliability of the several systems under comparison are taken into account in the cost by introducing sufficient redundancy in each case to achieve a specified probability of success.

(b) At the other extreme where mission costs are moderate and mission failure tolerable, repetition of the mission rather than the introduction of redundancy may be the most practical and least costly approach. The mission cost for this case is obtained by dividing the mission cost for 100 percent system reliability by the estimated system reliability.

Whether one uses procedure (a) or (b) is an individual consideration for each case. And, in some cases, a mixture of these two approaches may be the least costly; i.e., it may be advantageous to introduce some redundance, even if repetition of the mission is permissible.

o <u>Confidence of meeting mission IOC date</u>: The confidence of meeting the IOC date can be estimated from a consideration of the number of components in the system that are required to attain advanced performance. If all components are required only to attain current performance or modest extensions thereof, then the confidence is close to 100 percent. When the requirements on some components are advanced well beyond current state-of-art and also when novel components with no prior developmental background are introduced, then confidence in meeting the IOC date decreases. For example, at the start of the development of the aircraft nuclear propulsion system, a low confidence estimate would be appropriate because of the novel high temperature nuclear reactor. The confidence is expressed by a number between 1 and 0 where 1 represents perfect confidence.

- <u>Flexibility</u>: While the primary mission task may be closely prescribed, there may also be alternative tasks that warrant consideration. The several mission tasks may be assigned weight factors in accordance with an appraisal of their importance and each system in the comparison could be rated according to its capability in each of the mission tasks. The index of merit for each system would then be given by an equation such as discussed in the Appendix.

- <u>Future Potential</u>: Although the several systems under comparison can all perform the prescribed missions, they may differ in their potential for (a) growth in performance, and (b) unique performance capability. A rating system such as discussed in the Appendix may again be utilized.

- <u>Installation and Operational Qualities:</u> Qualities of a system, such as ease of installation, maintenance, operation, and favorable interface with other systems, should be recognized. Again a figure of merit as computed from an equation such as described in the Appendix may adequately represent this item.

- <u>Special Comment</u>: This space is only filled when a special consideration crucial to the decision is pertinent.

MATRIX REDUCTION AND JUDGMENT PROCESS

Table I illustrates the appearance of a decision matrix of the type described. It involves eight rows and a number of columns representing each of the competing systems, and it presents a formidable array of numbers to the eye. As pointed out in the introduction, an attempt to compress this information into a single number for each system by employing a figure of merit scheme (see Appendix) is not satisfactory because (1) it involves the mixing of numbers of basically different kinds and (2) it hides some of the information needed for a proper decision. (By the same token it must be borne in mind that equal rating numbers for different parameters in Table 1 do not carry equal importance and that the relative importance of these parameters changes with change in mission.) Instead of the figure of merit method for reducing the size of the matrix, another approach is presented in this paper.

Table 1

ILLUSTRATIVE DECISION MATRIX

Application of Propulsion Systems to Mission X

(Mission Initial Operational Date_____)

Parameters	Systems				
	A	B	C	D	E
1. System R&D Cost					
2. Mission Cost Effectiveness					
3. Decision Date					
4. Confidence in Meeting IOC Date					
5. Flexibility					
6. Potential					
7. Installation and Operational Qualities					
8. Special Comment					

Table 2

Rules for Matrix Reduction

1. When the values for a given parameter in the matrix for the various systems differ by an amount less than the accuracy of the estimate, these values are deleted from the matrix.

2. A system that is poorer than another on all remaining parameters has all its numbers deleted.

3. A zero for any quality parameter (e.g., items 4 to 7 of Table 1 inclusive) deletes the system. A zero is assigned to a parameter only when the system is unacceptable with respect to an item under this parameter that is crucial.

The application of these rules will be illustrated for the hypothetical case shown in Table 2. The parameters associated with five competitive systems in Mission X are listed as part of an exercise to determine the appropriate developmental decisions.

The reduced matrix is shown in Table 3 The mission costs and system R&D costs were eliminated because the differences were considered to be less than the accuracy of the estimates. System E was eliminated because of the zero in the flexibility parameter. With column E removed, the remaining values in rows 5 and 7 differ by less than the accuracy of the estimate and therefore were also eliminated. Systems A and D were eliminated because the remaining values were less than for Systems B or C. We now have left only two systems, B and C, the first with an advantage in confidence of m-ting the IOC date and the second with an advantage in potential. The decision dates were left in the matrix to facilitate discussion.

The evaluation of the data in Table 3 is then performed with the aid of the following rules.

Table 2

ILLUSTRATIVE COMPARISON OF SYSTEMS IN MISSION X

(Mission IOC date 1978)

Parameters	Systems				
	A	B	C	D	E
1. System R&D Cost $\$10^6$	50	55	60	56	54
2. Mission Cost $\$10^6$	1003	1010	1004	1000	1000
3. Decision Date	1970	1972	1971	1970	1970
4. Confidence of Meeting IOC Date	.70	.95	.60	.60	.70
5. Flexibility	.7	.7	.8	.7	0
6. Future Potential	.5	.5	.9	.5	.4
7. Installation and Operational Qualities	.6	.6	.7	.7	.8
8. Special Comment					

Table 3

REDUCED MATRIX CORRESPONDING TO TABLE 2

	A	B	C	D	E
1. System R&D Cost $\$10^6$	-	-	-	-	-
2. Mission Cost $\$10^6$	-	-	-	-	-
3. Decision Date	-	1972	1971	-	-
4. Confidence of Meeting IOC Date	-	.95	.60	-	-
5. Flexibility	-	-	-	-	-
6. Future Potential	-	.5	.9	-	-
7. Installation and Operational Qualities	-	-	-	-	-
8. Special Comment					

Judgment Guide Rules

A. IOC Date Rules

(1) When a firm IOC date exists for an important mission application, then a significant advantage in "confidence to meet IOC date" takes precedence over modest advantages in other items.

(2) When a firm IOC date exists for an important mission application and the two contending systems are, (a) a conventional system with high confidence of meeting the IOC date and, (b) a novel system with much greater future promise, but with less confidence of meeting the IOC date, then research and exploratory engineering should be performed on the novel system, at least up to the date of development decision, to provide an improved basis for a judgment of confidence in meeting the IOC date. This effort should, of course, continue even if a decision were made to develop the conventional system for the specific application under consideration if, at the date of decision, the results on the novel system are encouraging and important future applications are envisioned.

(3) When a firm IOC date for a mission application does not exist, then emphasis shifts to qualities like "future promise" provided that rating disadvantages in other items are not excessive. However, the decision is limited to the performance of research and exploratory engineering.

(4) When the confidence of meeting the IOC date is, at most, moderate for the several systems under comparison, then at least two systems that are acceptable on other items should be supported in research and exploratory engineering, at least to the date of development decision and possibly beyond this date, if confidence remains moderate.

B. Cost Rules

(1) A large advantage for a given system in total cost for a closely specified mission may be significant if there is much confidence

in the magnitude of the mission task predicated in the analysis or in the manner of performing the mission. However, absence of this confidence may shift emphasis to other comparison items.

(2) When the system R&D cost is very small compared with the mission cost, then, of course, a substantial advantage in mission cost would prevail over an advantage in system R&D cost.

(3) When the system R&D cost is a large part of the mission cost and when the magnitude of the mission task is uncertain and may be small, then a large advantage in system R&D cost, which in a sense represents the initial investment risk, should strongly influence the decision.

(4) When only minor differences in rating on all parameters occurs among the systems under consideration, obviously one would favor the system having the better ratings for the parameters of major importance to the mission under consideration. It is harder in this case to identify the optimum system with certainty, but, by the same token, the consequence of not choosing the optimum system is not serious.

The example shown in Tables 2 and 3 comes under the purview of Rule A-2. While System B shows a large advantage in confidence of meeting the IOC date, System C promises considerable improvement in future potential. Thus, if there is much confidence in the future utility of the proposed Mission X, then the indicated decisions are:

(a) Do research and exploratory engineering on System C until at least 1971, at which time a reappraisal of the confidence of meeting the IOC date is made for this system.

(b) If the confidence for System C is still low, a decision is appropriate for developing System B for Mission X. A decision to continue or stop the effort on System C would depend on the amount of progress made and the importance of its future application prospects.

(c) If, on the other hand, sufficient progress is made on System C by 1971 to indicate a confidence of meeting the required IOC date comparable to that of Mission B and a re-evaluation of the costs on the basis of this new information still shows no

no critical cost differences, then one would choose System C for development for Mission X.

The rules for matrix reduction presented in this paper represent in my mind only a beginning. They will not handle all cases. Hence, amplification and refinement of the rules can be anticipated as experience with the process grows. The rules for the judgment process are based on about 35 years of personal experience in research and development on flight propulsion systems and the emphasis in the rules presented herein reflects this somewhat narrow field of decision practice. (Some of the background for these rules appears in Ref. 2). The rules are admittedly arbitrary and limited because they represent a single observer's viewpoint in a very complex field. Again one must consider these rules as representing only a beginning to be amplified and modified as expertise and range of application grow.

Appendix

Figures of Merit

It is common practice to use the following equation for establishing a figure of merit in the comparison of various systems.

$$I^J = \left[\sum_{i=1}^{n} R_i^J W_i\right] / \sum_{i=1}^{n} W_i \tag{1}$$

where I^J = rating index of J^{th} system,

R_i^J = rating of J^{th} system on the i^{th} comparison parameter

W_i = weighting factor for the i^{th} comparison parameter

n = number of comparison parameters

If the rating R_i^J is assigned a value between zero and 1 where 1 represents a rating of excellent, then I^J is a number between 0 and 1. An objection to Eq. (1) is that when a large number of rating parameters are involved, a zero rating on a crucial parameter, which should have eliminated the system, would have only a minor effect on the overall rating value. This problem can be eliminated by employing the following equation

$$I^J = \left[\sum_{i=1}^{n} W_i / R_i^J\right]^{-1} \sum_{i=1}^{n} W_i \tag{2}$$

where the value of R_i^J lies between ϵ and 1. The value of ϵ is assumed to approach zero as a limit* and is assigned to a parameter only when the system under discussion is unacceptable on this parameter. Equation (2) has the objection (which is shared also by Eq. (1)) that it requires modification if relatedness exists between any of the parameters.

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*This refinement is introduced to avoid the problem of dividing by zero in Eq. (2) which mathematical purists say is not a defined operation. A value of ϵ (or 0 in the case of Eq. (1)) is assigned when the system is unacceptable on a crucial parameter.

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